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Online Loss Minimization in Distribution System Incorporating SSSC with Particle Swarm Optimization

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Abstract—*The major power lost in power system is occurred in distribution system. Increase in power loss has bad economic effect due to the energy wasted. It harms the consumer due to the drop in voltage, in addition the increase in power loss lead to increase in gas emission from thermal generating plant, therefore many efforts are consumed for minimizing the power loss in power system. In this paper, the static synchronous series compensator (SSSC) is incorporated in radial distribution system with one of the efficient artificial intelligence known as particle swarm optimization (PSO) to find the best phase angle for the injected voltage in order to minimize the power loss. The PSO program is interfaced with the proposed power system and the information is exchanged every specified period. This gives the system optimization and monitored from time to time.*
Keywords— Online Loss Minimization, Swarm Optimization, SSSC, PSO.

I. INTRODUCTION

The study of power loss minimization takes a wide area of optimization researches, however most of these researches dealing with steady state or offline cases. In fact, the variables in power system such that, load angles, voltages, currents, and the loads may vary from time to time so the information need to be updated. In this paper the optimization method updates their information directly from the system and gives the best solution within a specified period. Power loss minimization can be categorized under the optimization of power flow. The optimal power flow (OPF) is introduced firstly, by Carpentier in 1962 in order to minimize the production cost [1]. However, in addition to the production cost, the objective(s) of OPF take a various type in the recent years some of them are (1), minimization the emission of the harm gases, (2) power loss minimization, (3) minimization the size of FACTS devices, (4) minimization of voltage deviation, etc.

OPF may have one objective or extended to a multiple objective [2]. Most of the OPF problems are solved in steady state or off line, where in this paper the optimization is done directly (actively) for the system and the control variables are setting online in order to minimize the transmission loss taking into account the bus voltages as an inequality constraint. The increase in transmission loss may be occurs due to the large amount of reactive power consumed by the loads. The increases in power loss lead to decrease in bus voltages, in other hand the drop in voltages cause further increase in power loss. Typically, the power loss in transmission system should not exceed 6 percent in the health network [3]. Power loss minimization in distribution system can be achieved by reconfiguration the network [4] or by setting the control variables such that tap setting of distribution transformer, reactive power compensation by switching fixed capacitors [3, 5]. Incorporating FACTS devices or distribution generators in modern power system will affect the transmission loss, in the other hand the optimal placement of these devices increases this effectiveness and reduces the size of them [6, 7].

The solution of optimal power flow, incorporating FACTS devices, is done by simulate these devices into equivalent circuit suitable for power flow equations [8, 9, 10]. Many authors used one of the last versions of FACTS (i.e., SSSC, STATCOM, UPFC, and IPFC), with equivalent circuit incorporated in optimal power flow equations in order to achieve the optimal solution and satisfy the objective function minimization [9- 11].

In this paper, the SSSC is represented by a voltage source connected in series with the system, the solution is made by calculating the total transmission loss as function of the injected voltage then find the optimal phase angle of this voltage to satisfy the objective of OPF using PSO method. The data of the network parameters is registered while the node voltage and associated phase angles are imported from

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the system directly.

II. THE PROBLEM OF OPF

Optimal power flow problem is a nonlinear optimization problem. It consists of a nonlinear objective function defined with nonlinear constraints. The optimal power flow problem requires the solution of nonlinear equations, describing optimal and/or secure operation of power systems.

The general optimal power flow problem can be expressed as a constrained optimization problem as follows.

Minimize $f(x)$

Subject to $g(x) = 0$, equality constraints

$h(x) \le 0$, inequality constraints

By converting both equality and inequality constraints into penalty terms and therefore added to form the penalty function

$$P(x) = f(x) + \Omega(x) \qquad \dots (1)$$

$$\Omega(x) = \rho\left[(g(x))^2 + \max(0, h(x)^2\right] \qquad \dots (2)$$

Where

$P(x)$ is the penalty function

$\Omega(x)$ is the penalty term

ρ is the penalty factor

By using a concept of the penalty method [12], the constrained optimization problem is transformed into an unconstrained optimization problem in which the penalty function as described above is minimized.

Objective Function

Although most of optimal power flow problems involve the total production cost of the entire power system, in some cases some different objective may be chosen [5, 13]. In this paper, the power transmission loss function is set as the objective function. The power transmission loss can be expressed as follows.

$$P_{loss} = \sum_{i=1}^{n} g_{ij}\left[V_j^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right] \qquad (3)$$

Where Vi is the voltage magnitude at bus i

$g_{i,j}$ is the conductance of line i-j

δ_i is the voltage angle at bus i

n is the total number of transmission lines

III. PARTICLE SWARM OPTIMIZATION METHOD

Kennedy and Eberhart developed a particle swarm optimization algorithm in1995 based on the behavior of individuals (i.e., particles or agents) of a swarm [14, 15]. Its roots are in zoologist's modeling of the movement of individuals (i.e., fish, birds) within a group. It has been noticed that members of the group seem to share information among them to improve the direction of the group to their desired target. The particle swarm optimization algorithm searches in parallel using a group of individuals similar to other AI-based heuristic optimization techniques. Each individual corresponds to a candidate solution to the problem. Individuals in a swarm approach to the optimum through its present velocity, previous experience, and the experience of its neighbors. In a physical n-dimensional search space, the position and velocity of individual i are represented as the velocity vectors. Using the information of individual i and its updated velocity can be modified under the following equations in the particle swarm optimization algorithm

$$v(i) = v(i) + c_1 r_1 [pbest(i) - x(i)] + c_2 r_2 [gbest(i) - x(i)] \qquad (4)$$

$$x(i+1) = x(i) + v(i) \qquad (5)$$

Where, c_1 and c_2 are learning factors (weights), r_1 and r_2 are uniformly random numbers between 0 and 1. The procedure of the particle swarm optimization can be summarized in the flow diagram of Fig. 2

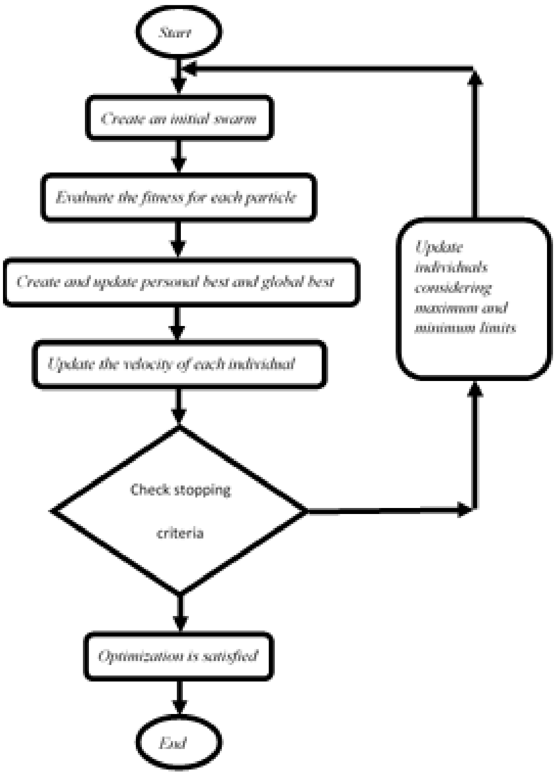

Fig.1: Particle swarm optimization method.

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IV. INCORPOERATING SSSC IN DISTRIBUTION SYSTEM

The Static Synchronous Series Compensator (SSSC) is a series connected FACTS controller based on VSC and can be viewed as an advanced type of controlled series compensation. A SSSC has several advantages over a TCSC such as (a) elimination of bulky passive components - capacitors and reactors, (b) improved technical characteristics (c) symmetric capability in both inductive and capacitive operating modes (d) possibility of connecting an energy source on the DC side to exchange real power with the AC network [16]. SSSC is a device which can control simultaneously all three parameters of line power flow (line impedance, voltage and phase angle) [17]. This device is a VSC's connected in series with the transmission line through a series transformer. The VSC's in turns are connected with each other through a dc link as shown in Fig (2). The series inverter can be applied to control the real and reactive line power flow and voltage with controllable magnitude and phase in series with the transmission line. Practically at yet, SSSC is installed in power system as a part of UPFC or Convertible Static Compensator [16]. Also many researches deals with the design a controller circuit of the selected FACTS device to improve voltage profile and minimization transmission loss, in [11] and [18] the authors used an UPFC to improve bus voltage and power loss and developed the complex mathematical equations with some restricted assumptions to design a controller. In this work the injected voltage of SSSC is controlled using s-function of MTLAB with PSO to obtain an optimal phase angle for minimum loss.

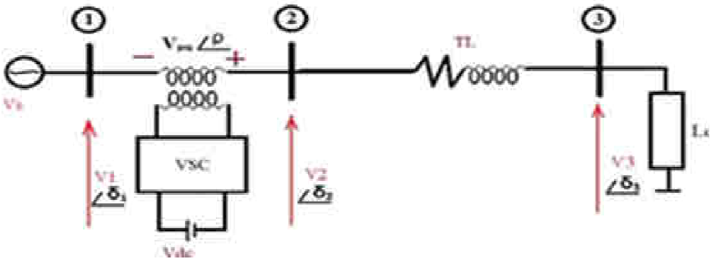

Fig.2: Proposed radial distribution system with SSSC.

V. SIMULATION AND RESULTS

As shown in Fig (3), the PSO is incorporated in Simulink via s-function and the information is exchanged every specified period.

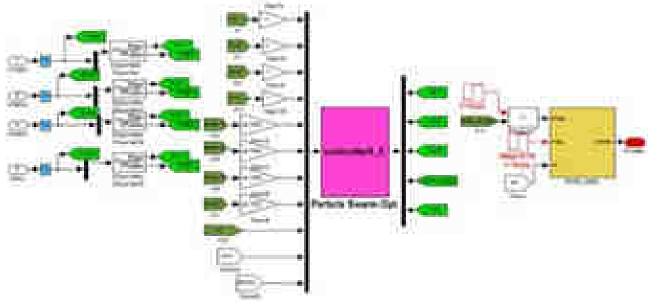

Fig.3: SSSC controller using PSO method.

In order to prove the validity of this method the equivalent circuit of the radial system with injected voltage is considered and the relation between the injected voltage and transmission loss, using eq. (3), is correlated as shown in Fig(4). It is evident that the minimum loss had been satisfied at injected phase angle (ρ) equal 180 degrees at load angle (δ) equal zero

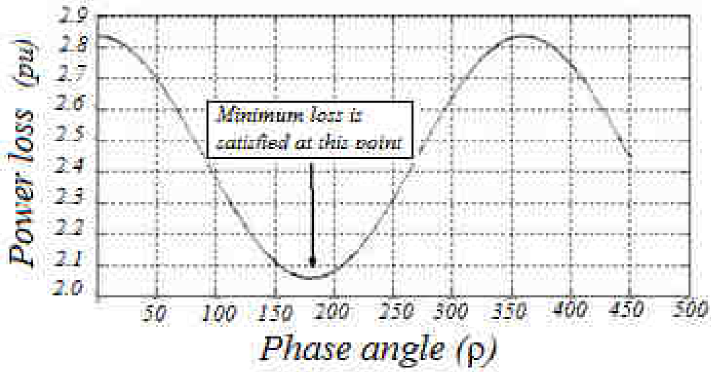

Fig.5: Represents the PSO convergence firstly at ρ =180 degree at δ=zero degree, then, after a specified period, the load angle is changed to be δ=40 degree so the optimizationprogram response to find the new injected voltage angle of 220degrees.

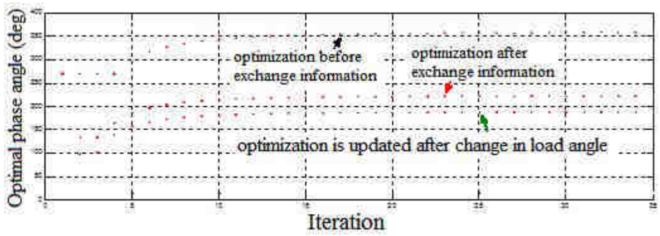

Fig.5: PSO interfaced with the system to find the best angle

After the calculation of the best angle the value is exportthrough the output bus within a specified period adjusted sothat it suitable for the operation time and control response asshown in Fig (6). If the period is so small then

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PSO repeatedtoo much, in the other hand if the period is too large, then theresponse become very slowly.

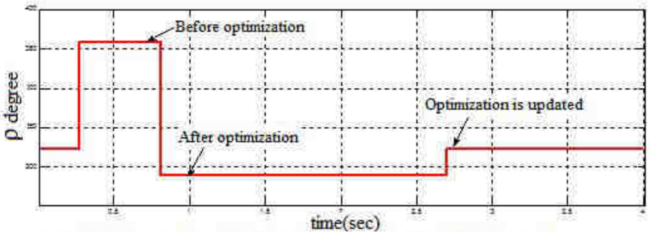

Fig.6: Best injected phase angle exported to VSI.

The effect of SSSC on power loss using PSO comparedwith the identical circuit without optimization is represented inFig (7), it is shown that when the SSSC receives the value ofthe best angle at t=1sec, the power loss reduced about 0.2 pu.At t=2.1sec, the load angle is increased and the power loss is increased too. The PSO program find the new best angle and the SSSC receives the order at t=2.75 sec as shown to effect thepower loss again.

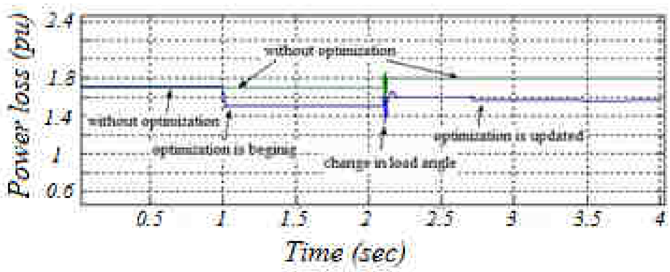

Fig.7: Power loss minimization using SSSC with PSO.

VI. CONCLUSION

The use of SSSC with PSO in radial distribution system hasthe evident effect for minimizing transmission power loss.Apply the new method for directly (online) optimize the powerflow in distribution system success for monitoring the loss in the system and minimizing it after a short period and this canbe applied on the large and complex network.

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